SOIL AND BEDROCK SENSITIVITY TO ACIDIC DEPOSITION

in the Northwest Territories

REPORT TO ACCOMPANY MAP

Northwest Territories Renewable Resources

SOIL AND BEDROCK SENSITIVITY TO ACIDIC DEPOSITION IN THE NORTHWEST TERRITORIES

August, 1986.

SUMMARY

This report accompanies an interpretive map for the Northwest Territories entitled Potential of Soils and Bedrock to Reduce the Acidity of Atmospheric Deposition in the Northwest Territories.

The map identifies the potential buffering capacity of individual terrain units in the Northwest Territories. Depending upon the chemical composition of the soils and bedrock within each land unit, acidic atmospheric deposition may or may not be altered by the terrestrial system. Surface waters in areas identified as having a High Potential to Reduce Acidity are unlikely to experience acidification owing to the ameliorative effects of the typical limestone bedrock and/or deep calcareous surficial deposits. Areas of Low Potential are underlain by granitic bedrock and/or covered by deep noncalcareous materials. While surface waters may be naturally acidic in this environment, any further addition from the atmosphere will not be buffered by the surrounding environment but will be added to the aquatic regime, placing an added stress on the system.

ACKNOWLEDGEMENTS

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INTRODUCTION

This project is one of a series of maps produced under the guidelines established by the Coordinating Committee on Soil and Geology Sensitivity Mapping for the Western Canada Long Range Transport of Air Pollutants (LRTAP) Technical Committee (Wiens 1983). In order to ensure compatability and comparability between provincial and territorial maps, the guidelines have been followed as closely as possible. Methods and criteria are based on those employed in the sensitivity assessment of Eastern Canada (Cowell and Lucas 1985, Cowell et al. 1981, Lucas and Cowell 1984, MOI 1983). Since the Northwest Territories presents an environment very different from the southern situation, some modifications to the methodology were necessary. Any such modifications are identified and described in detail in the text of this report.

DATA AVAILABILITY AND RELIABILITY

Data suitable for a sensitivity assessment of the Northwest Territories are often considered scarce and sparse, largely being derived from small-scale mapping projects and a few detailed and site specific soil or geology reports (scales ca 1:25,000 to 1:125,000). The Ecodistrict Data Base, developed by Environment Canada, did provide a suitable framework for the mapping analysis and, when coupled with published and unpublished information did provide adequate data for project completion at the mapping scale of 1:5,000,000.

Since 1972, Lands Directorate, Environment Canada, has compiled environmental information and in coordination with their own field surveys, produced an ecological mapping base. The base unit of these maps is the Ecodistrict, an area characterized by distinctive patterns of relief, geology, geomorphology, vegetation, soils, water, and fauna. Ecodistrict maps have been produced through the Northern Land Use Information Series (NLUIS) Maps at a scale of 1:250,000 and through the Regional Ecological Land Surveys in the Beaufort Sea, Mackenzie Mountains and the Northwest Passage. Published maps exist for all of the Districts of Mackenzie and Keewatin and about half of the Arctic Islands. Draft Ecodistrict maps at 1:1,000,000 and limited preliminary information were available for most of the remaining Arctic Islands. Interpretation of Landsat imagery was undertaken in a few areas where base information was virtually nonexistent.

Geological reports and maps and soil surveys were consulted and cross-checked with the information contained in the Ecodistrict Data Base during the data compilation phase of the project. This was done to ensure data compatability and comparability for all areas. A list of the data sources incorporated into the interpretation is included in the Bibliography.

A reliability index on the map illustrates the relative reliability of the sensitivity assessment based on the scale and quantity of available data sources. Interpretations for areas for which published NLUIS maps were evaluated in conjunction with Geological Survey of Canada (GSC) and soil survey reports are believed to be the most reliable.

CRITERIA SELECTION

Based on a review of the current literature and discussion with researchers in the field of sensitivity mapping, Cowell et al. (1981) identified a number of criteria as significant in determining the effects of acidic deposition on the aquatic

system. Specifically, these are 1) exchangeable bases in the soil; 2) soil depth; 3) soil drainage; 4) landform relief; 5) vegetation type; 6) vegetation cover; and 7) underlying material, either the parent material or bedrock. The complete data set is presented in Table 1, along with their appropriate class limits. Ideally, factors should be combined to produce a single sensitivity rating for each land map unit, however, the precise nature of the combined interactions between these factors has not yet been fully described. In addition, the very number of possible combinations and permutations of these factors precludes manual manipulation and interpretation.

Three criteria have been identified as significant components for the delineation and interpretation of 'sensitive areas' (Lucas and Cowell 1984). Each map unit requires information for the following: soil chemistry, soil depth (including percent exposed bedrock), and bedrock type. Where there is insufficient or incomplete data, surrogate variables need to be substituted. Although the preferred soil chemical data are exchangeable bases, this information is nonexistent on a regional scale and a surrogate was required. Soil depth and bedrock data in various forms were available for most of the Northwest Territories.

Soil Chemistry

Texture has been used as a surrogate for or as a measure of soil chemical properties, including cation exchange capacity and exchangeable bases (Cowell et al. 1981; Cowell and Lucas 1985; Lucas and Cowell 1984). In previous 'sensitivity interpretations', sands and other coarse materials (eg. granite-derived tills and deposits from noncalcareous sandstone), were generally considered to have a low carbonate content and thus, a low potential to reduce the acidity of atmospheric deposition. Clays and similar fine-textured deposits (eg. lime-rich lacustrine and marine sediments), were interpreted as having a high carbonate content. These soils were then rated as having a high potential to reduce the acidity of atmospheric deposition. Similarly, mixed and moderate-textured deposits were assigned a moderate carbonate content and given a moderate potential rating.

Although this substitution of texture for soil chemical properties may be valid for the majority of environments typical to Eastern Canada, certain modifications were required when evaluating northern land areas. In the Arctic coarse- and very coarse-textured materials were frequently identified as fragmented limestone surficial deposits. These materials have a high carbonate content although according to the textural classification scheme outlined above they would be rated as having a low carbonate content. Texture alone was insufficient to define the potential chemistry of the surficial materials. Parent material and mode of origin were required to adequately define soil chemistry.

Classification of the soil chemical surrogate(s) required a two-step procedure. This is shown in Table 2. Initially, textural information from the original data sources was grouped into fine, coarse, very coarse and mixed categories. Following the intent outlined in Table 1, the fine class included all clays and loams (except sandy loam). The coarse category encompassed silts, sands and sandy loam. Blocky and fragmented materials were assigned to the very coarse fraction. This class had not been defined in previous interpretations. The mixed textural group is indicative of a variety of materials identified within a small area.

Once grouped, this textural data was combined with material mode of origin to derive the chemical surrogate. Fine sediments of marine origin were thought likely to contain significant quantities of calcareous material, and were assigned a high

TABLE 1: TERRESTRIAL FACTORS AND CRITERIA FOR DETERMINING THE POTENTIAL OF TERRESTRIAL ECOSYSTEMS TO REDUCE THE ACIDITY OF ATMOSPHERIC DEPOSITION (after Cowell et al 1981).

Terrestrial Factors	Potential to Reduce Acidity of Atmospheric Deposition		
	High	Moderate	Low
Soil Chemistry			
Exchangeable Bases (meq-100 g -1) Surrogates	>15	6-15	<6
Family Particle Size and pH in water	Clayey, pH >5.0; loamy, pH >5.5; all calcareous soils	Clayey, pH 4.5-5.0; loamy, pH 5.0 - 5.5; sandy, pH >5.5	Clayey, pH <4.5; loamy, pH <5.0; sandy, pH <5.5
Texture	Clay, silty clay, sandy clay (>35% clay)	Silty clay, loam, clay loam, sandy clay loam, silt loam, loam (10% to 35% clay)	Silt, sandy loam, loamy sand, sand (<10% clay)
Cation Exchange Capacity (meq-100 g -1)	>25	10 to 25	<10
$SO_4^{=}$ Adsorption Capacity	High sulfate adsorption and low organic matter, and high Al_2O_3 and/or Fe_2O_3 + Fe_3O_4 content		Low sulfate adsorption and high organic matter, and /or low Al_2O_3 and/or Fe_2O_3 + Fe_3O_4 content
Soil Depth (cm)	>100	25-100	<25
Soil Drainage	Poor	Imperfect to well	Rapid
Landform Relief	Level	Rolling	Steep
Vegetation	Deciduous	Mixed	Coniferous
Vegetation Cover	Continuous (>60%)	Discontinuous to sparse (20-60%)	Sparse to barren (<20%)
Underlying Material			
Parent Material	Carbonate bearing	Noncarbonate bearing	Noncarbonate bearing
Bedrock Material	Limestone, dolomite, and metamorphic equivalents, calcareous clastic rocks, carbonate rocks interbedded with noncarbonate rocks	Volcanic rocks, shales, greywackes, sandstones, ultramafic rocks, gabbro, mudstone, metaequivalents	Granite, granite gneiss, orthoquartzite, syenite

carbonate content rating. Inland, marine-influenced deposits within the coastal plain were rated moderate for similar reasons. In the absence of other information, glacial deposits (moraines and till plains) in the Districts of Mackenzie and Franklin consisting of coarse, very coarse and mixed materials were assigned a ranking of moderate. This assumes the incorporation of at least some carbonate-rich debris in the moraine composition; a likely conclusion given the distribution of limestone bedrock throughout much of the area. It is recognized that the chemistry of such areas may be underestimated. Where the origin of glacial deposits could be specifically traced to predominantly limestone terrain, the resultant morainal materials were assigned a high carbonate content rating. This interpretation required detailed geological survey reports and was limited to small areas scattered throughout the Northwest Territories. Within the District of Keewatin glacial materials of all textures were not considered to contain appreciable quantities of calcareous materials and were evaluated accordingly. The rating for coarse, very coarse and mixed residual and colluvial deposits reflects the surrounding bedrock chemistry. Fluvial sediments of all textures were usually identified as having a low carbonate content, unless located within an extensive area of carbonate-rich bedrock.

Soil Depth

Soil depth was defined as deep, greater than 1m; shallow, less than 1m but greater than 10cm; or barren, less than 10cm following the format in Table 1. These corresponded to the blanket, veneer and bare classes defined within the Ecodistrict framework. Mixed depths and undifferentiated soils were assigned to the shallow class. In the absence of soil/surficial material depth information, estimates were made based on the mode of origin of the deposit. Hummocky tills, drumlinized ridges and eskers were considered deep as were most marine, fluvial and colluvial deposits. Residuum and till plains with common and/or frequent bedrock outcrops were classified as shallow materials. Bedrock outcrops covering greater than 20% of the polygon were identified separately.

Bedrock

Background bedrock information was provided by the Geological Map of Canada (Map 1250A) with refinements from many detailed mapping reports and Ecodistrict data. Bedrock types were assigned to one of four categories, previously defined by Shilts et al. (1981) and outlined in Table 3. Although bedrock information is lacking in some areas, these coincided with ice fields and glaciers. The absence of these data did not hinder the interpretation.

Permafrost

The effects of permafrost on the sensitivity interpretation have not been dealt with directly. The specific nature of the effects of permafrost on surface water chemistry are not known, although it could be assumed that the frozen layer creates an impermeable layer at some depth. Any surface runoff percolating to depth would flow along the ice/surficial deposit interface rather than at the soil/bedrock interface as assumed in the analysis of Eastern and Southern Canada. This is interpreted as a reduced influence of bedrock in terrains with shallow surficial materials or areas underlain by limestone.

TABLE 2: CLASSIFICATION PROCEDURE FOR SOIL CHEMISTRY SURROGATE.

STEP 1		STEP 2	
Texture From Original Data	Generalized Texture	Mode of Origin	Carbonate Content
clay, loam (excluding sandy loam)	fine	glacial	high
		marine	high
		fluvial	low
silt, sand, sandy loam	coarse	fluvial	low
		glacial	moderate
blocky, fragmented	very coarse	marine	moderate
		residual	as per bedrock
		colluvial	as per bedrock
all combinations	mixed	residual	as per bedrock
		colluvial	as per bedrock

This classification assumes no detailed information as described in the text.

DATA COMPILATION AND MAPPING PROCEDURES

All data were compiled onto ozalid copies of 1:1,000,000 NTS Series base maps for the NWT. Ecodistricts were used to define the basic mapping polygons. Where Ecodistricts did not appear to reflect the diversity in bedrock and soils identified by the data, new units were constructed. This occurred almost exclusively at the boundaries between NLUIS (Ecodistrict) 1:250,000 map sheets.

Each map unit was coded according to soil texture, soil depth, mode of origin and bedrock type. Any inconsistencies between or within data sources were identified and resolved at this level. Where more than one combination of the variables was found in a single polygon, compound units were created. These identified the percent coverage for each of the two dominant combinations. The secondary combination had to cover at least 20% of the map polygon in order to be included in the analysis.

Individual map units were then combined where two or more polygons were coded similarly and shared a common boundary. These new composite polygons were delineated at 1:1,000,000.

By overlaying a reduction of the Ecodistrict lines on the 1:5,000,000 stable mylar base, the final polygon boundaries were transferred to the final mapping scale. Where the map units could not be delineated at the small-scale, additional compound polygons were created by combining two contiguous polygons. This most frequently occurred along the shoreline.

POLYGON CLASSIFICATION

The sensitivity of each map unit is denoted on the final map by a two-digit code. The first letter indicates the assigned sensitivity rating; the second digit identifies the specific combination of attributes contained within that polygon. The three sensitivity categories identify areas of High, Moderate and Low Potential to Reduce the Acidity of Atmospheric Deposition. Polygons consisting of Ice and/or Organic Deposits were not evaluated, but rather labelled accordingly.

Each combination of soil chemistry (or its surrogate), soil depth and bedrock were assigned to the high, moderate or low class according to Table 4. Subdivisions within each of the three sensitivity classes are not meant to infer any specific ranking in their relative ability to reduce acidity. They are descriptive and are designed to allow any subsequent interpretations to be performed without having to reevaluate the entire original data set.

INTERPRETATION

Low Potential to Reduce the Acidity of Deposition

All of the areas identified as having a low potential to reduce acidity are characterized by terrain with no appreciable overall buffering potential. Although the soils may be deep, they have a low carbonate content. The underlying bedrock may contain some calcareous material, but it is considered that most drainage waters will not reach the bedrock/soil interface, and thus, has little effect on the net buffering potential (Class L1 and L2). Where soils are predominantly shallow, surface water may penetrate to bedrock and be altered by the chemistry of that bedrock.

TABLE 3: BEDROCK CLASSES (after Shilts et al. 1981).

Bedrock Type	Polygon Classification
Limestone, marble, dolomite	1
Carbonate-rich siliceous sedimentary: shale, limestone; noncalcareous siliceous with carbonate interbeds: shale, siltstone, dolomite; quartzose sandstone with carbonates	2
Ultramafic, serpentine, noncalcareous siliceous sedimentary: black shale, slate chert; gabbro, anorthosite, diorite; basaltic and associated sedimentary; mafic volcanics	3
Granite, gneiss, quartzose sandstone, syenite and associated alkalic rocks	4

TABLE 4: SURFICIAL AND BEDROCK CHARACTERISTICS AS MAPPED.

Potential to Reduce Acidity	Map Class	Soil Depth	Soil Carbonate Content**	Bedrock Type***
LOW	L1	deep	low	2, 3, or 4
	L2(H)*	deep	low	1
	L3	shallow	moderate	4
	L4	shallow	low	4
	L5(M)*	shallow	low	2 or 3
	L6	barren	variable	4
MODERATE	M1	deep	moderate	2, 3, or 4
	M2(H)*	deep	moderate	1
	M3	shallow	high	2 or 3
	M4	shallow	high	4
	M5	shallow	moderate	2 or 3
	M6(H)*	shallow	moderate	1
	M7(H)*	shallow	low	1
	M8	barren	variable	2 or 3
HIGH	H1	deep	high	1, 2, 3, or 4
	H2	shallow	high	1
	H3	barren	variable	1
ORGANICS	O1			1
	O2			2
	O3			3
	O4			4
GLACIER/ICEFIELD				1, 2, 3, or 4

* adjusted sensitivity rating for areas of discontinuous permafrost reflects the increased influence of bedrock

** interpreted from texture and mode of origin; 'variable' indicates any individual class or any combination of classes

*** classes as defined by Shilts et al. (1981); refer to Table 3.

Shallow soils of low and moderate carbonate content overlying Type 4 (eg. granite) Bedrock (Class L3 and L4) and shallow soils of low carbonate content overlying Type 2 and/or 3 (those with limited buffering capabilities) Bedrock (Class L5) are also believed to have low potential to reduce acidity. Class L6 terrain units are essentially exposed bedrock (Type 4). Surficial materials are limited in areal distribution and are unlikely to contribute significantly to the buffering potential of the map polygon.

Moderate Potential to Reduce the Acidity of Deposition

All deep soils of moderate carbonate content will have a moderate potential to reduce acidity (Class M1 and M2). Shallow soils of high carbonate content overlying Type 2, 3, and/or 4 Bedrock (eg. not limestone), are assigned to the moderate category. Although there may be significant buffering potential in the thin covering of surficial materials, the overall potential to reduce acidity of the map unit will be less than the H2 class (where Type 1 Bedrock is near the surface). The differentiation of the M3 and M4 classes is based on bedrock type and may or may not result in varying relative buffering potential. Similarly, shallow soils of moderate carbonate content overlying Type 1, 2, and/or 3 Bedrock (eg. not granite), and shallow soils of low carbonate content overlying Type 1 Bedrock will have greater buffering potentials than the L3 and L4/5 classes, respectively and are thus, assigned to the moderate category.

High Potential to Reduce the Acidity of Deposition

Deep soils with high carbonate content have a high potential to reduce acidity, regardless of the underlying bedrock (Class H1). Surface waters will be chemically altered by the soil prior to any possible interaction at the bedrock/soil interface. Drainage water passing through shallow soils of high carbonate content overlying Type 1 Bedrock (Class H2) and barren limestone plains (Class H3) are also likely to undergo significant modification.

Organics

The influence of naturally acidic terrain on the amelioration of acidic deposition is unknown. The effects may vary depending upon the nature of the organic deposit (bog, fen, or marsh), chemical and physical properties of material (CEC, bulk density), depth of organic matter, type and abundance of buried mineral deposits, underlying bedrock and the hydrologic regime of the organic terrain. In the absence of detailed information on the organics found in the N.W.T. and a better understanding of the processes (chemical and physical) involved, organic terrain has been identified but not assessed.

Glacier/Icefield

Glacial waters will generally have little buffering capacity or low nutrient content and in this sense have low potential to reduce atmospheric derived acidity. However, due to the lack of national consensus and the paucity of literature or knowledge of the distribution of categories of glacial water chemistries, the sensitivity of permanent icefields and glaciers have not been assessed in this analysis.

Permafrost

It is assumed that permafrost in the soil forms an impermeable barrier to the vertical movement of water and may be interpreted as a reduced influence of bedrock in terrains with shallow surficial materials. Allowances for the presence of permafrost have been made in the interpretation. To avoid confusion, the legend and map shadings reflect the presumed presence of permafrost throughout the Northwest Territories. The sensitivity rating may be adjusted for those five map units [L2, L5, M2, M6 and M7], where the absence of permafrost is thought to significantly alter the buffering effect (Table 4). These reflect the increased influence of bedrock where surface water can penetrate to the bedrock interface.

Specifically, the L2 class delineates deep soils with a low carbonate content overlying limestone or similar material. In the northernmost areas, permafrost will inhibit percolation to depth and the chemistry of the runoff water will not be affected by the presence of the underlying limestone. However, in the southern regions of N.W.T. where permafrost is discontinuous or absent, it can be assumed that water will percolate to bedrock depth and be buffered by the limestone. This can be incorporated into the analysis by adjusting the rating from Low to High Potential to Reduce Acidity. The overall buffering potential of the L5 class will also be increased under non-permafrost conditions. The sensitivity rating may be amended to moderate (from low) to reflect the added buffering potential afforded by the underlying Type 2 and/or 3 Bedrock.

Similarly, the assessment of the M2, M6, and M7 classes may be amended. It should be noted however, that of the five categories, only the L5 class occurs with any frequency within discontinuous permafrost areas. The other four classes are almost exclusive to high Arctic areas.

In a comparison of the Soil Map of Canada (Clayton et al. 1977) with the Soil and Bedrock Sensitivity Map, there does not appear to be a strong correlation between soil orders and sensitivity assessment. Soils of much of N.W.T. has been classified as Turbic Cryosols (rocky and stony phases), and these have been interpreted as having high, moderate or low potential to reduce acidity. Other regions of low potential include those of Dystric Brunisols and a small area of Humo-Ferric Podzols in southeastern District of Mackenzie. Moderate areas seem to be most closely associated with Fibric Organic Cryosols, although the distribution of these surficial deposits appears to be underestimated by the present analysis. Turbic Cryosols in the north and Eutric Brunisols in the Mackenzie Mountains account for most of the land area identified as having a high potential to reduce acidity.

Overall, the sensitivity map shows better correlation with the bedrock geology owing to the predominant shallowness of the surficial materials. Areas of low potential throughout the District of Keewatin and Baffin Island are associated with Type 4 bedrock, granite and granitic gneiss. In the high Arctic and western District of Mackenzie, shallow and limited deep deposits overlay bedrock of Types 1, 2, and 3. Deep and shallow carbonate-rich materials are most often, but not exclusively, found over Type 1 bedrock (limestone). These comprise the high potential class.

CONCLUSIONS AND RECOMMENDATIONS

The analytical methods and data used in this analysis were appropriate for the end product at the final scale (1:5,000,000). The classes identified are regional

evaluations and are not meant to be interpreted for individual or specific sites. The sensitivity assessment reflects the general terrain characteristics and their presumed influence on surface water chemistry. No attempt should be made to derive larger scale maps from the finished product without consultation of the individual data sources.

Future sensitivity assessments of Arctic areas should attempt to define more precisely the effect of permafrost on surface and subsurface drainage, and the ultimate influence on water-soil-bedrock interactions.

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GENERAL REFERENCES

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The following references have specifically been utilized in the interpretation of potential to reduce acidity for lands in the Northwest Territories. This is not meant to be a comprehensive listing of all available reports, maps. etc. Numerous other studies, particularly those conducted prior to 1965, have been omitted but have previously been synthesized into the "Ecological Overview" component of the Northern Land Use Information Series. The following references, organized by "Soils" and "Geology", provide information on soil depth, soil chemistry, surficial deposit texture and genetic origin, and on bedrock type. Additional references, which were used in the identification of organic soil areas, are listed under "Multidisciplinary Surveys".

A complete listing of Northwest Territories Geological Survey of Canada reports, papers and maps is updated annually and published as "Index to Reports: Northwest Territories" and is available from the Geological Survey of Canada.

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